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Structural Damage of Masonry Wall of Palace Type Buildings in Earthquake

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ABSTRACT: *In the Gorkha Earthquake 2015 that occurred in Nepal, several buildings were damaged and collapsed in Kathmandu valley. Kathmandu valley (Bhaktapur, Lailtpur and Kathmandu) is well known for its traditional palaces, temples and residential buildings. These palaces were constructed mainly of brick masonry with mud or shurkhi mortar, and the next major construction material used was timber. Most of the palaces and buildings of Kathmandu valley are of Malla period(around 300 years old). Other buildings are also more than 100 years old. During Gorkha Earthquake 2015, a number of these types of palaces were damaged and collapsed in the core city and outer area of Bhaktapur, Kathmandu and Lalitpur of Nepal. Photographs of damaged and collapsed of masonry palaces were collected after the earthquake. Different damage types of the palaces are shown. Structural system of these masonry palaces are studied and causes of failure are determined. It is found that the main causes of failure of brick masonry buildings palace type buildings are the lack of proper structural integration systems, decay of construction materials and seepage of water.*

KEYWORDS: *Brick Masonry Palaces, Gorkha Earthquake 2015, Structural Damage Study, Masonry Wall Palace Type Buildings, Failure Type.*

I. INTRODUCTION

Nepal lies in earthquake prone zone. The Himalayas are very vulnerable to earthquake. Due to the incessant convergence of Indian Plate towards the Eurasian Plate, Nepal has experienced great earthquakes in the past. In 1934 earthquake, large destruction of masonry structures had occurred. In the past, almost all of the palaces and buildings were constructed with brick masonry in mud or surkhi mortar in city area. In addition to that, timbers were used in different palaces. Stone masonry in mud mortar was constructed but they were very few in city areas. People built different palaces, temples and their residences by their own experiences and practices. The kings during Malla and Rana regime constructed different palaces for their residences and official purposes.

Scope of the Work : Most of the old masonry buildings that were not constructed properly were damaged severely. A number of masonry palace buildings with the damages of different levels can be observed in different places of Kathmandu valley. This article is focused in studying the damages of masonry palace type buildings in the Kathmandu Valley due to the Gorkha Earthquake 2015. The effects of earthquake in masonry palace type buildings in Kathmandu Valley are identified.

II. RECENT GORKHA EARTHQUAKE 2015

An earthquake of M7.8 occurred 77 km NW of Kathmandu (in the border of Gorkha and Lamjung) at 11:56 on 25 April 2015 with shallow depth of 15 km and maximum Mercalli Intensity of IX, lasting approximately fifty seconds. More than hundreds of aftershocks have occurred since the magnitude 7.8 earthquake in Nepal on April 25, 2015. Nepal faced continuous aftershocks throughout the country at the intervals of 15–20 minutes, with one of the major aftershocks reaching a magnitude of 6.7 on 26 April at 12:54:08. The largest aftershock experienced was a magnitude of 7.3 that occurred 18 km south-east of Kodari with the epicenter in the border of Dolkha and Sindhupal chowk district at 12:51 on 12 May 2015. The 1833 and 1934 earthquakes represent the most recently occurring largest historical earthquakes on this portion of the plate boundary. It was recorded that officially 8,857 and in total 9018 people were dead and 21,952 injured. Ancient monuments in the Kathmandu Valley listed in UNESCO world heritage sites got collapsed including some at Bhaktapur Durbar Square, Kathmandu Durbar Square, Patan Durbar Square, Changu Narayan Temple and Swayabhunath Stupa. The 7.8-magnitude earthquake completely damaged 1,38,182 houses across Nepal and partially damaged 1,22,694 other homes. Out of them, 10,394 government buildings collapsed and over 13,000 government buildings were partially damaged, according to Nepal Home Ministry sources.

Field Survey : The location for the field survey of damaged buildings due to recent earthquake is chosen as Kathmandu Valley since the most affected areas were identified to be in this region. During the field visit damage palace type buildings were observed. General information and surrounding of selected building was collected from global overview. Photographs of the damaged buildings were taken. After that, the damages on structural and non-structural elements were studied. Engineering judgment was used to quantify the severity of the damages. Finally, the possible causes of damage were pointed out.

III. TYPES OF FAILURES OF MASONRY PALACE STRUCTURES

There are several types of failures of masonry structures. Building may fail in different ways. For example: failure of foundation, main load bearing walls, interior load bearing masonry walls, staircase, floors, floor failure, corner failure etc. Building might also fail due to the deterioration of materials, weak maintenance of building.

OBSERVATIONS AND CAUSES OF STRUCTURAL FAILURES

Out of Plane Failure of Building: Most of the old masonry buildings are weak in out of plane action. Mainly, in the top floor, the types of roof used are galvanised iron sheet in timber purlins. Purlins are rigidly connected to the wall. At the top of the wall near roof, there are no any horizontal or inclined timber bands. Due to the improper connections between roof and brick masonry at the top and the lack of connection in both the directions of the masonry wall, out of plane failure might have occurred. This situation is shown in figure 6.1.1. Another side of building failure at the top is of the same nature as shown in figure 6.1.2. All the outer corridor walls got failed and collapsed to the outer side since the top of the corridor columns were not connected properly in the horizontal direction (See figure 6.1.3). Masonry building of Basantapur Durbar (figure 6.1.4) shows out of plane failure of outer wall due to poor connection in between roof and floor level. In Main palace of Basantpur, Gadhi Baithak also fail in vertical crack due to the out of plane failure (figure 6.1.5).

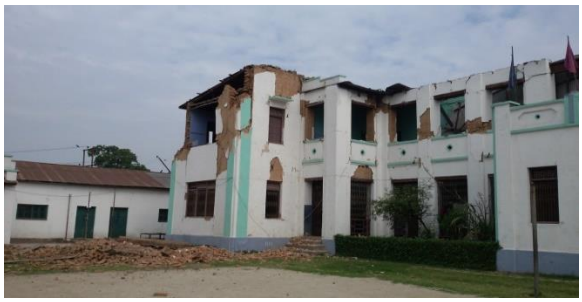

Figure 6.1.1. Out of plane failure

(Shree Padma High School, Darbar Square, Bhaktapur)

Photo source: Rajan Suwal

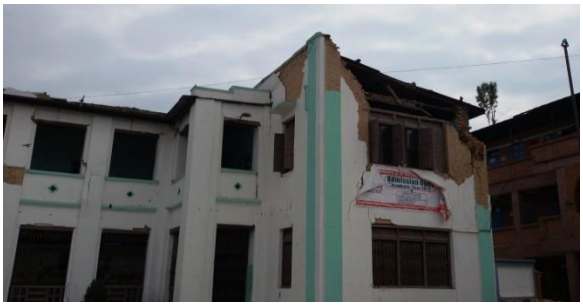

Figure 6.1.2. Out of plane failure

(Shree Padma High School, Darbar Square, Bhaktapur)

Photo source: Rajan Suwal

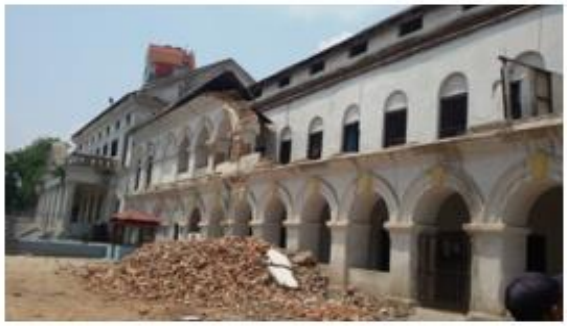

Figure 6.1.3: Out of plane failure

(Darbar High School, Ranipokhari, Kathmandu)

Photo source: Rajan Suwal

Figure 6.1.4: Out of plane failure

(Basantapur Darbar, Darbar Square, Kathmandu)

Photo source: Rajan Suwal

Figure 6.1.5: Out of plane failure
(Gadhi Baithak, Darbar Square, Kathmandu)
Photo source: Rajan Suwal

Shear Failure of Building Columns: Brick columns in huge openings are very weak in earthquake. In floors, earthquake load is resisted by thick brick wall. Where there are big openings in brick masonry, horizontal stiffness is drastically reduced which caused failure of brick column which is shown in Figure 6.2.1 and Figure 6.2.2.

Figure 6.2.1: Column failure
(Shree Padma High School, Darbar Square, Bhaktapur)
Photo source: Rajan Suwal

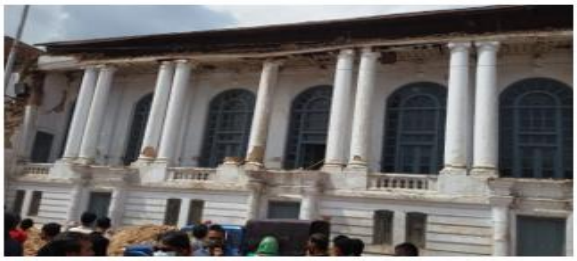

Figure 6.2.2: Column failure
(Gadhi Baithak, Basantapur Darbar Square, Kathmandu)
Photo source: Rajan Suwal

Corner Failure of Building: At the junction of two buildings, a separation in the form of seismic gap is required. Buildings which have different mass and stiffness have different time period and frequency. In the direction of high stiffness, the chances of deflection is less and another building with less stiffness deflects more. Because of this, at the junction of masonry buildings, we can observe failure which is shown in figure 6.3.1. When a building is closely constructed with courtyard at the middle, stiffness of buildings in all the directions will not be the same, and hence, cracks will be developed at the joint of junction partially or in overall height. Crack is developed in the joint of junction of two sides which is shown in figure 6.3.2 in the building of Keshar Mahal, Kathmandu. In this building in the north wing joint it is observed the crack from roof to ground floor.

Figure 6.3.1:Corner failure
(Darbar High School, Ranipokhari, Kathmandu)
Photo source: Rajan Suwal

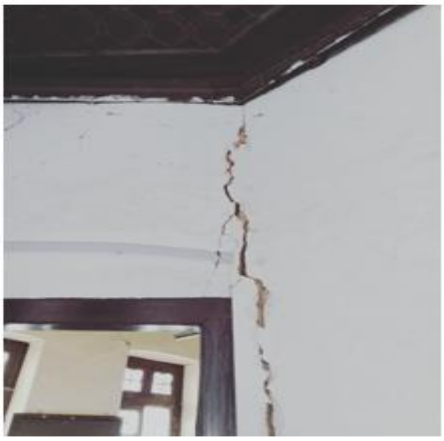

Figure 6.3.2:Corner failure
(Keshar Mahal, Kathmandu)
Photo source: Rajan Suwal

Vertical Shear Failure of Masonry Wall: When window opening width is small with respect to its height and spacing between top and bottom opening is not sufficient, in this case vertical shear failure occurs in masonry structure. Remaining brick work height cannot be resisted the applied shear. This type of failure can be seen if Figure 6.4.1, Figure 6.4.2 and Figure 6.4.3.

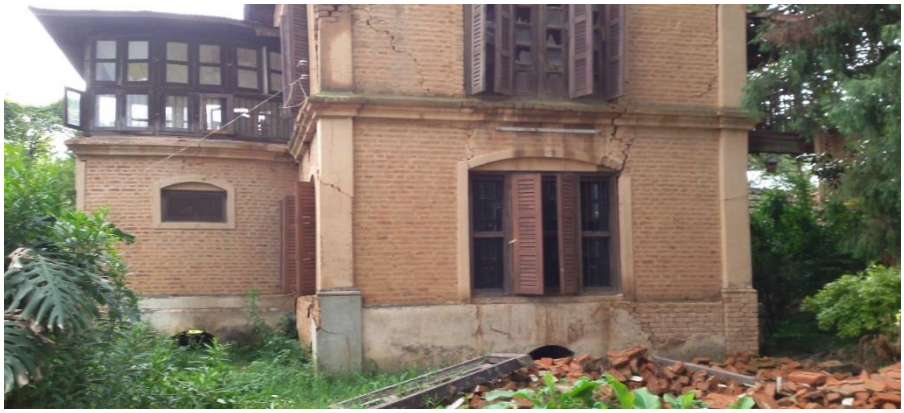

Figure 6.4.1:Vertical shear failure over opening

(Judha palace building, Tinchuli, Kathmandu)

Photo source: Rajan Suwal

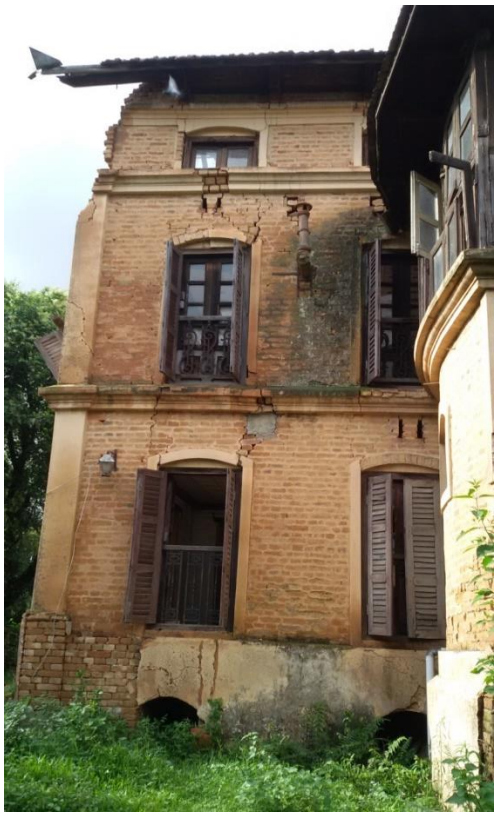

Figure 6.4.2:Vertical shear failure
(Judha building, Tinchuli, Kathmandu)
Photo source: Rajan Suwal

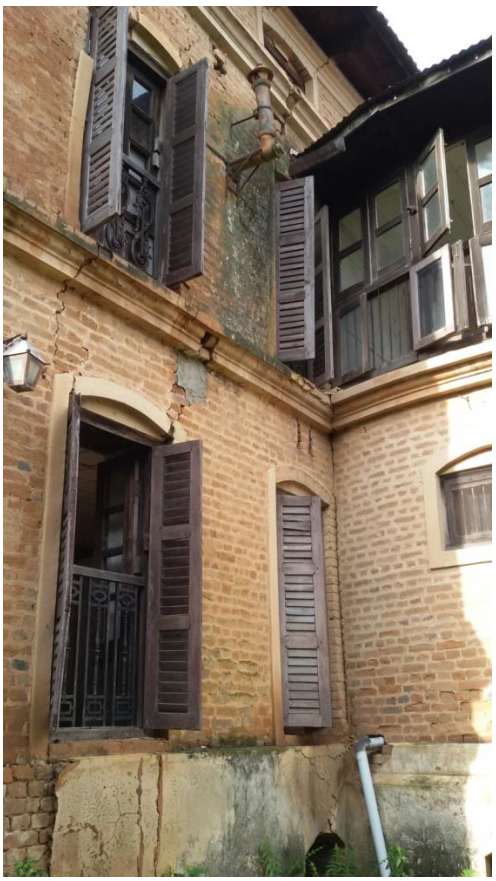

Figure 6.4.3: Other view of vertical shear failure
(Judha building, Tinchuli, Kathmandu)
Photo source: Rajan Suwal

Roof Gable End Wall Failure: In most of the masonry buildings, gable end walls are not connected with main wall properly. Roof rafters and purlins are not connected strong enough. Horizontal and inclined timber bands are not provided. Due to it gable end wall of palace buildings were damaged due to inertia force of this weak part of triangle wall in earthquake. This type of phenomena can be seen in Figure 6.5.1 and Figure 6.5.2.

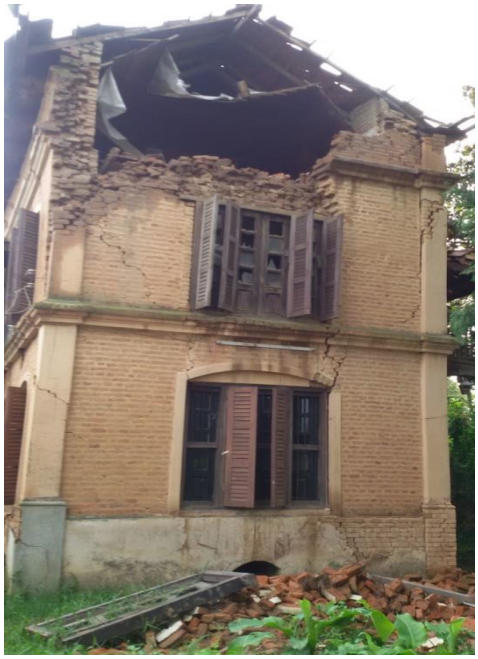

Figure 6.5.1: Gable end wall of roof failure
(Judha palace building in Tinchuli, Kathmandu)
Photo source: Rajan Suwal

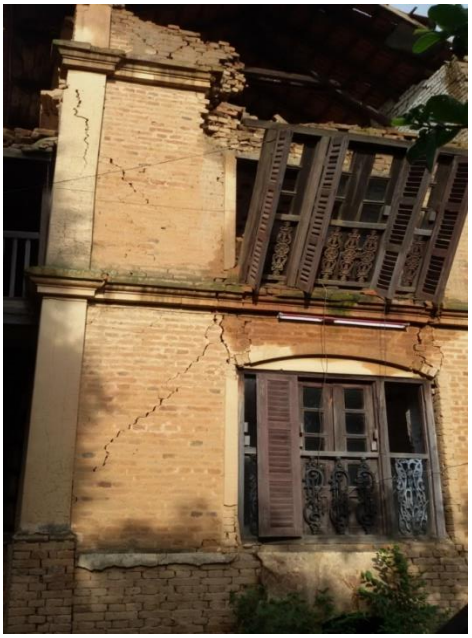

Figure 6.5.2: Gable end wall of roof failure
(Judha palace building in Tinchuli, Kathmandu)
Photo source: Rajan Suwal

Arch Failure of Masonry Building : Arches are mostly used in old brick masonry palaces and buildings. It is used in the corridors, inside and outside openings. In the time of earthquake, the top area of arches are mainly damaged because it is comparatively weak in shear in perpendicular direction as well as vertical direction. Arches failed at crone or from side. It is shown in figure 6.6.1, figure 6.6.2, figure 6.6.3 and figure 6.6.4.

Figure 6.6.1: Arch failure in main entrance
(Keshar Mahal Palace, Kathmandu)
Photo source: Rajan Suwal

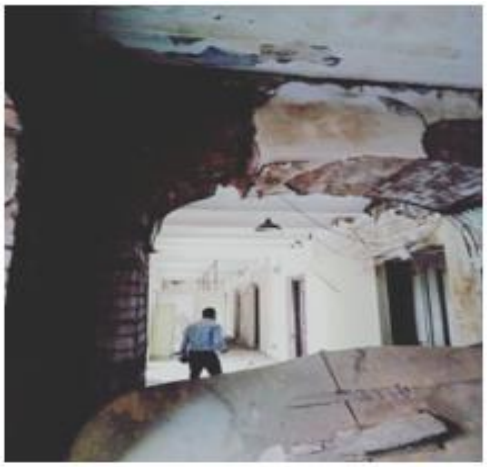

Figure 6.6.2: Arch failure in corridor
(Keshar Mahal Palace, Kathmandu)
Photo source: Rajan Suwal

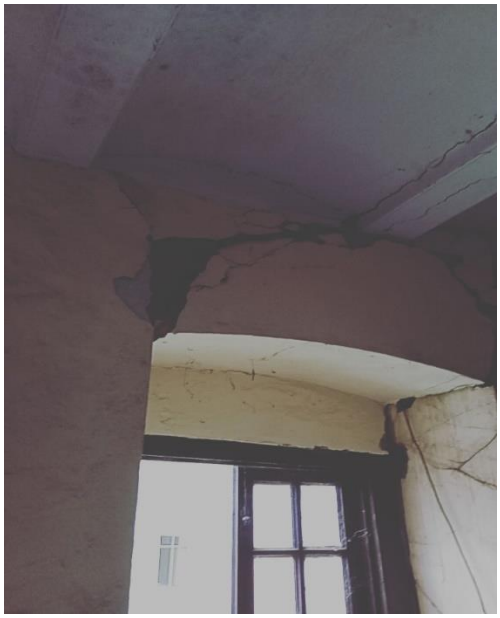

Figure 6.6.3: Arch failure in corridor
(Keshar Mahal Palace, Kathmandu)
Photo source: Rajan Suwal

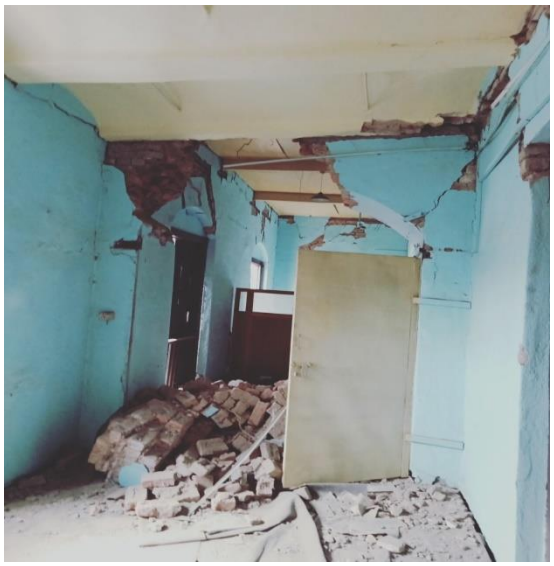

Figure 6.6.4: Arch failure in corridor
(Keshar Mahal Palace, Kathmandu)
Photo source: Rajan Suwal

Failure in Joint of Old and New Masonry Wall: In the certain old type of palace buildings front whole face were repaired keeping internal walls untouched. In the process of construction there were no proper bonding between old and new masonry wall therefore it is observed that there is vertical crack in the earthquake. (See figure 6.7.1)

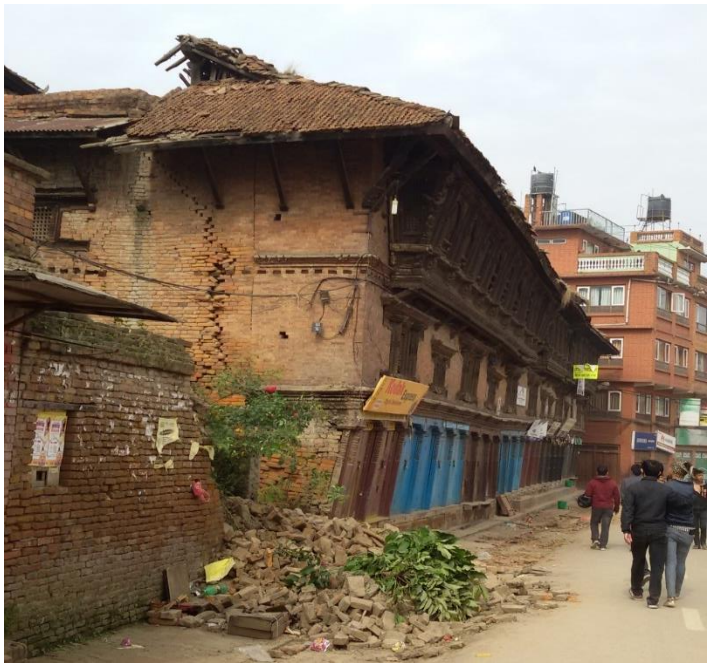

Figure 6.7.1: Vertical crack in masonry wall in old and
new joints of construction
(Khauma, Bhaktapur)
Photo source: Rajan Suwal

Delamination of roof and walls : In the most of the palace type masonry buildings it can be seen that there is water seepage from the roof. Most of the roofs were made of galvanised iron sheet and some were made of timber with telia bricks. Due to not proper maintenance of roof, delamination in roofs and walls are observed. Wooden part of roof fails due to decay(see figure 6.8.1). In figure 6.8.2 it is seen that wall of top floor of Keshar Darbar is weak condition due to water seepage from roof.

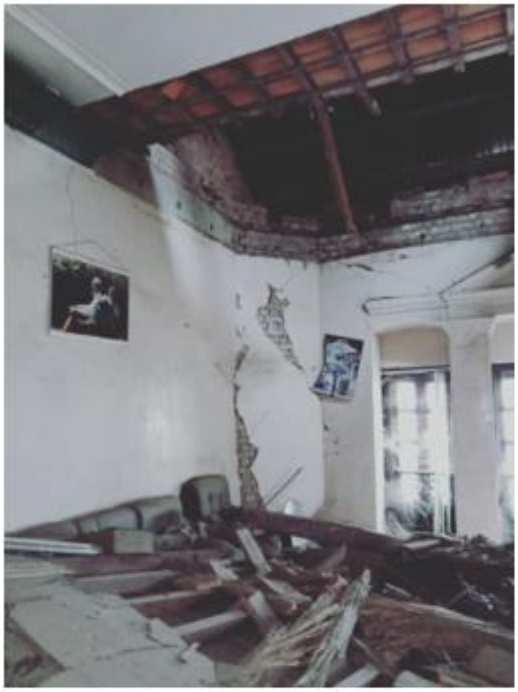

Figure 6.8.1: Falling of roof due to decay of timber
(Keshar Mahal Palace, Kathmandu)
Photo source: Rajan Suwal

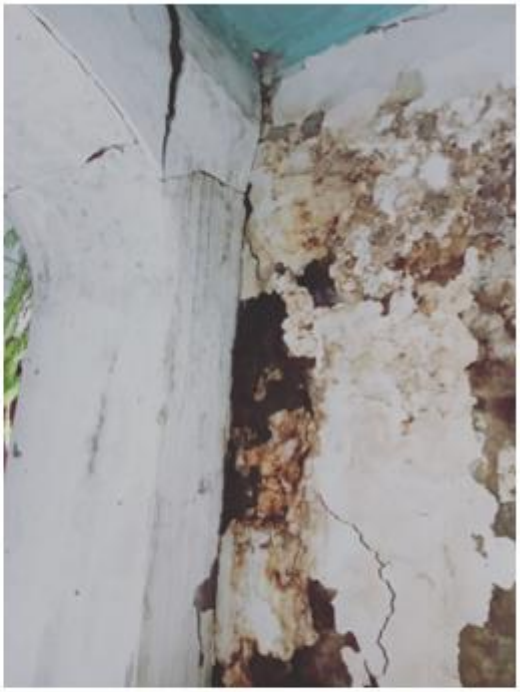

Figure 6.8.2: Deterioration of wall due to water Seepage
(Keshar Mahal Palace, Kathmandu)
Photo source: Rajan Suwal

IV. CONCLUSION AND RECOMMENDATION

1. In most of the old masonry buildings of palace type it is observed that out of plane failure due to not proper connection of floors and walls. Walls are more slender which leads to fail.
2. Buildings which have slender masonry columns and were constructed for load bearing or decorative purpose failed due to the not sufficient in lateral stiffness in earthquake load.
3. Corner failure of most of the building was occurred due to irregular shape of building. It can be avoided making separation in simple regular figures.
4. In same vertical line of high openings make weak in shear of masonry above opening. It would be better to reduce the height of opening and keep higher sill level of windows.
5. In most of the slender masonry buildings, gable end wall failed due to weak connection between gable wall and rafter frame. There was no timber bandage in inclined part of gable end walls.
6. Arches of masonry wall in old masonry palace type building seem weak due to less shear resistance capacity. It is required to strengthen with bigger size or stronger material.
7. Continuous joint of old and new masonry building seems weak in earthquake. It is recommended to make joint in different horizontal and vertical level keeping timber joint to make stronger.
8. Old palace type of masonry buildings, it is observed that delamination of building occurs due to water seepage. Because of it timber roof decayed and wall were deteriorated. Therefore it is recommended to do the periodic maintenance of roof and other parts of structures.

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